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The Edwards Aquifer: Water for Thirsty Texans

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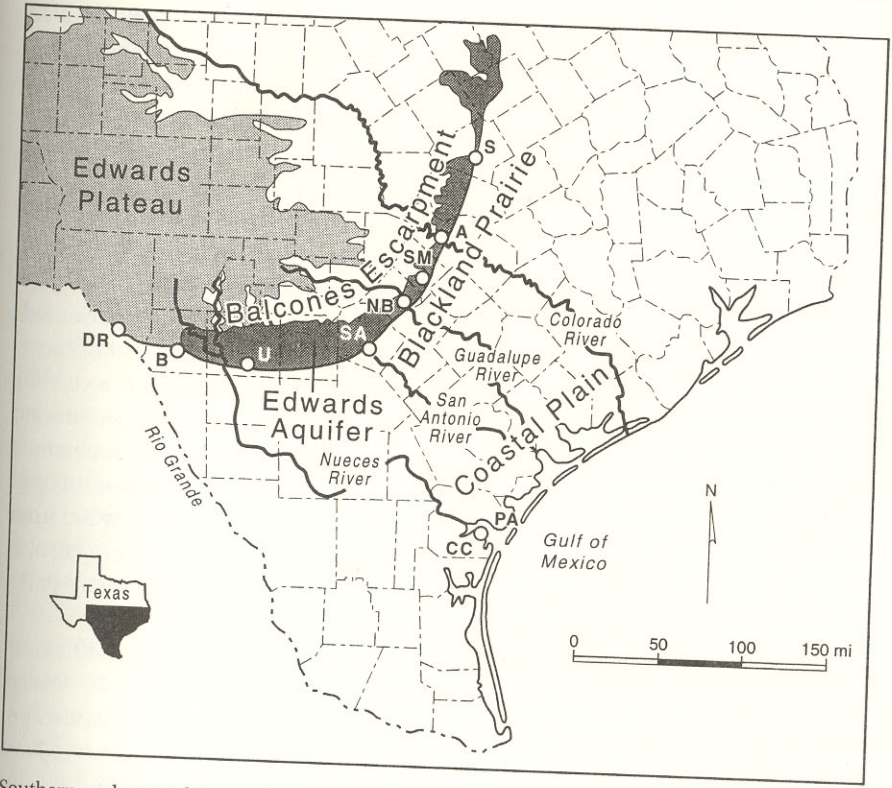
Water is our most precious natural resource. Without drinkable water, civilization and life as we know it would cease to exist. In the drier parts of the planet, the presence of reliable sources of drinkable water dictates where and how we live. This is true, for instance, in central, southern, and western Texas.

As one drives up Interstate 37 from the bays, estuaries, beaches, and sand dunes of Port Aransas on the Gulf of Mexico into southern and central Texas, one travels through a subtle variety of landscapes. Near the coast, the land is quite flat and the climate is subtropical. Ship channels in Corpus Christi reveal the varied industry of the area as passing oil tankers dwarf fishing boats. Driving north, one passes gently rolling farmland and cattle range of the Coastal Plain into the Blackland Prairie. The fertile soils of these provinces are developed on sands, silts, and clays that were deposited from rivers and the shallow Gulf of Mexico, whose shoreline migrated with changing sea level over the past 140 million years.

Farther inland, as one reaches San Antonio in central Texas, the climate becomes drier, and western counties experience semiarid conditions, with less than 20 inches of rainfall each year. The landscape becomes hilly as one passes over the few hundred feet of elevation of the Balcones Escarpment, which was produced by faulting in the Earth's crust 15 to 20 million years ago. Standing on the escarpment looking south and east, one gazes out on the Blackland Prairie. To the north stretches the more rugged Edwards Plateau, which is built by flat-lying limestone strata that are dissected by streams. On this plateau, there is sufficient rainfall to support some agriculture and cattle ranching; it hosts a rural, low population-density economy. Along the base of the escarpment are the region's major cities and towns, including San Antonio and Austin. More



Southern and central Texas, showing the location of the Edwards Aquifer and the Edwards Plateau. Cities and towns are identified by letters: Del Rio (DR), Brackettville (B), Uvalde (U), San Antonio (SA), New Braunfels (NB), San Marcos (SM), Austin (A), Salado (S), Corpus Christi (CC), and Port Arkansas (PA).

than fortuity caused humans to congregate here. Cities and industries require dependable, large volumes of water, and springs feed larger streams along the base of the escarpment. Water is present there because of the region's unique geology, its configuration of rocks and faults. The limestones and associated strata that transmit water to and from the surface compose the Edwards Aquifer, the source of water for the region. The streams, springs, and aquifer are ultimately fed by rainfall from storms.

Rainstorms occur when warm, moist tropical air from the Gulf of Mexico encounters cooler, drier air as it moves northward or as it moves over and is lifted by the Balcones Escarpment in central Texas. Some of the most intense rainfalls in U.S. history have occurred along this escarpment. For example, 38 inches of rain fell in 24 hours near the town of Thrall in 1921. High temperatures and long periods between such storms, however, cause significant dry spells. Studies of historical records show that prolonged dry periods leading to drought are also part of the natural climatic cycle here.

From Del Rio on the Mexican border, east through Brackettville, Uvalde, San Antonio, New Braunfels, San Marcos, and Austin, to Salado, each city is located where major springs issue from the Edwards Aquifer. The aquifer's springs provided a reliable source of fresh water in a region where both river flow and rainfall vary considerably. The obvious relief that the cool spring waters and surrounding dense, wooded vegetation must have brought to early inhabitants of this area was emphasized during the summer of 1998, when the region experienced 26 consecutive days with temperatures of 99°F or higher. Early settlements bordering the Edwards Plateau along the Balcones Escarpment relied on these fresh water sources, and fierce conflicts between Confederates, Comanches, Apaches, Kickapoos, European immigrants, and desperados were influenced by the hydrogeology of the area.[1] Until large reservoirs were constructed in the twentieth century, the major cities developed around the springs and utilized their waters. We still use the springs for water obtained from wells drilled into the Edwards Aquifer. In fact, over two million people, including residents of the city of San Antonio, still get their drinking water from the Edwards. The spring systems and the streams that issue from them are also vital to the culture of these areas. Although some springs have gone dry, parks and recreational areas in the cities center on the springs.

Rapid development and population growth are now occurring in this area. Demand for water has grown and is expected to escalate dramatically. Fueled by a growing technology industry, a varied recreational and cultural landscape, wide-open spaces, fresh air, and mild winters, the population of the general Austin–San Antonio area is projected to double by the year 2025. Will the Edwards Aquifer be able to sustain the water needs of this growing population? Will we be able to develop and enact adequate management and use plans that will conserve water and protect its quality? Or, will we have struggles over water, as our forebears had?

ANATOMY OF AN AQUIFER

Aquifer means "water bearer" in Latin. The term is commonly mentioned in the modern media and therefore a precise definition of aquifers matters for a number of reasons. For instance, a "sole source aquifer" has a certain legal status because there are no viable alternative sources of water where that aquifer exists. Also many aquifers have been degraded or contaminated by human activity and must be cleaned up by the responsible party. Geologists define an aquifer as a body of geological material, such as sand, soil, or rock that yields usable amounts of adequate quality water to wells or springs. An aquifer must have holes in it to hold the water; that is, it must be porous, like a sponge. The pores must also be big enough and interconnected sufficiently to allow water to flow easily through the sand, soil, or rock. The extent of connectivity of the pores is called permeability. Not all geological materials have ample porosity, enough permeability, or satisfactory water quality to form an aquifer. The

Edwards, however, is an exceptional aquifer as a result of the way it was developed over the course of 100 million years.

Today, several hundred feet of carbonate rocks make up the Edwards Aquifer. Carbonates refer to rocks, such as limestones or dolostones, or other sedimentary deposits that are composed mainly of the minerals calcite, aragonite, or dolomite. During the early Cretaceous Period, approximately 100 million years ago, the sediments that would eventually be compressed to form the carbonate rocks were formed on an ancient shallow-water marine shelf. The setting was probably similar to that of the Florida Keys, the Bahamas, and the Arabian Gulf in which carbonate deposits accumulate today. Deposition during the Cretaceous occurred during a time when global sea level was so high that the ancestral Gulf of Mexico flooded into central Texas and much of central North America. The deposits that formed during this time period contained reefs that were dominated by clams, called rudistids, that had unusually shaped shells. Fossils of these now-extinct clams and a variety of other clams, snails, sea urchins, algae, and small one-celled organisms called foraminifera are common in some beds—or stratigraphic layers—within the Edwards Aquifer. Occasionally, the tops of some beds are marked by the trackways of dinosaurs that trod through the muddy sediment. Some soft-bodied, shrimplike organisms left their mark in the sediments in the form of burrows, which reveal the foraging and dwelling environments of these creatures. In the sediments, pathways with different porosities and permeabilities were created by these burrows and by the spaces between fossils.

Sea levels fluctuated during the Cretaceous, so at times of low sea level these marine sediments were exposed to the atmosphere. During times of exposure and periodic rainfall, some fossil shells were dissolved, and small caves and other dissolution features formed before the seas again covered the rocks. Occasionally, tidal flats and shallow lagoons of vast extent formed and beds of soluble minerals, such as gypsum, formed by evaporation of seawater. At other times, the seas were deep enough to allow great coiled ammonites and mosasaurs to swim above the sediments. Today, the layer of rock above the Edwards Aquifer is the Del Rio clay. This rock was formed by the compression of volcanic ash that settled in quiet waters. The permeability of Del Rio clay is so low that, wherever the clay is present, water cannot flow through it, either into or out of the aquifer. The Del Rio clay serves to confine the aquifer. Where the aquifer rocks are exposed to the land surface, the aquifer is said to be a water-table aquifer, or to be unconfined. The presence or absence of the Del Rio clay has important hydrologic and land use implications for people of this region, because a well drilled into a confined aquifer usually is less susceptible to contamination.

Some 45 million years after the end of the Cretaceous Period of high sea level and carbonate and clay deposition, the Edwards Aquifer rocks were fractured, faulted, and exposed to rainfall and erosion at the Earth's surface as a result of the faulting that produced the Balcones Escarpment. The soluble rocks again began to dissolve. Nodules of gypsum and other soluble minerals were dissolved, and the porosity of the rocks that contained the nodules increased. In addition to the porosity and permeability created by the original pores between and within fossils and burrows in the Edwards strata, rainfall that infiltrated the Edwards enhanced preexisting pathways of permeability—zones of dissolved gypsum, original pores, fault-induced fractures, and horizontal breaks (known to geologists as bedding planes) that separate rock strata. These pathways sped up dissolution of the carbonate rocks. Advanced dissolution formed conduits and caves that often are found aligned along the fractures and bedding planes. These dissolution features give the Edwards Aquifer its tremendous permeability. As a result of the faulting and uplift, streams cut down through the limestone, the water table was lowered, and caves were drained. Today, rainfall percolates down through soils and carbonate rocks, dissolves some of the carbonate minerals, drips into the caves, and slowly deposits calcite in the form of stalactites, stalagmites, and flowstones, which are collectively called speleothems.

In a general sense, the Edwards Aquifer is simple. Water gets into it from the rainfall percolation process just described. In addition, "losing" streams—those which flow over carbonate outcrops and sink into the stream bed—add water to the aquifer. However, this process only happens in the permeable rocks exposed in the unconfined zone; otherwise, the overlying Del Rio clay

Dissolution features in the Edwards Aquifer. The large pores were produced by dissolution of portions of the rock layer; these pores often follow patterns of preexisting shells or burrows of marine organisms that occurred in the original sediment deposited more than 65 million years ago. (*Photograph by John M. Sharp*) stops percolation. The Edwards differs from most aquifers in that most of the water—almost 80 percent—that gets into—or recharges—the aquifer is from losing streams. Water flowing in stream channels sinks into cracks or sinkholes, so recharge is locally restricted and, therefore, unevenly distributed.

The Edwards Aquifer is shaped like a crescent moon, with its concave side facing to the northwest. It ends to the north because there the Cretaceous carbonate rocks that form the aquifer have been eroded away. The southern boundary of the aquifer is termed the bad-water zone, because there the water in the aquifer is too salty to be used as drinking water. This salinity is natural and does not result from human activities. In the regions of the aquifer near San Antonio and Austin, salty brines migrate up from compacting sediments in the subsurface under the Gulf of Mexico. Near the Rio Grande, saltiness occurs simply because the groundwater dissolves soluble minerals in the aquifer, especially gypsum, along its flow path and introduces mineral salts into the system. There is considerable concern that saltwater from the bad-water zone will migrate into the aquifer and increase its saltiness. However, monitoring has shown that the position of the bad-water zone has been quite stable, even in times of drought.[2] This stability exists because the rocks in the bad-water zone have substantially lower permeability than most of the rocks of the aquifer, because high flow rates in the aquifer push saltier waters south, and because the bad-water zone abuts relatively impermeable, crushed rocks along a fault.

Groundwater flow in the Edwards Aquifer runs mostly along fractures or dissolution zones that are oriented along the Balcones Escarpment. Also, like landscapes carrying surface water, aquifers can have divides. The Continental Divide separates the surface waters that flow to the Pacific Ocean from those that flow to the Atlantic. Every river or stream has its own particular divides. Groundwater divides separate groundwater that flows to one natural outlet from groundwater that flows to another outlet. Groundwater cannot flow across a divide, just as surface waters cannot flow over the Continental Divide. The Edwards Aquifer contains three divides, which separate the aquifer into three distinct groundwater flow regions. From each of these, water leaves the aquifer at big springs or wells. The largest and most politically sensitive segment of the Edwards Aquifer is that which encompasses the largest area and includes the city of San Antonio. This segment of the aquifer provides the majority of water for municipal and agricultural purposes.

COMPETING DEMANDS FOR AQUIFER WATER

Competition for the water from the Edwards Aquifer is intense. The greatest users of water pumped from the aquifer are municipalities and agriculture; they use 89 percent of aquifer waters. Individual wells for domestic use and industry pump the remainder. There are, however, important uses of Edwards waters that depend on the natural spring outflows.

Water from the Edwards Aquifer is desirable because it is uncontaminated, has low salinity, and is very cheap to produce. Such a rapidly urbanizing environment, however, challenges our ability to maintain both water quantity and water quality. Construction of roads, parking lots, and buildings impact water quality because the increase in impervious cover (i.e., pavement) decreases the filtering and water retention capacity of the landscape. In addition, the greater residential and industrial activity above the aquifer produces more chemical and particulate waste. This pollution is a special concern in limestone aquifers such as the Edwards whose enhanced porosity and permeability allow wastes to spread rapidly as groundwater flows along conduits. Few alternative water sources for the region exist, and they will be very expensive to access.

Although few farmers in Texas irrigate their land, any water used for irrigation represents consumptive use. That is, water is not returned to the streams or groundwater, but instead goes into the atmosphere via plant respiration. Another agricultural use is aquaculture. The largest naturally flowing well in the world, at 40,000 gallons per minute, taps the Edwards Aquifer—it was once used to fill ponds for farming catfish.

In Texas, groundwater belongs to the landowner, who can use as much as desired as long as it is used in a "reasonable" manner, as defined by the courts. When criticized for their high water use, farmers have rightly pointed out that growing food benefits people, whereas lawn irrigation, the largest use of water in cities, is wasteful. As our cities grow rapidly, and as residential grass lawns replace native plant species adapted to the semiarid climate, the amount of water used for keeping grass green will continue to grow at a prodigious rate.

The natural spring systems provide important recreational and social amenities for the municipalities that cluster around them. Major urban parks are often built adjacent to the springs, and they host water sports, bathing, fishing, and hiking. To lose natural spring flows, as has already occurred for the San Antonio and San Pedro Springs in San Antonio, is both undesirable and politically unpopular.

Flows from the streams that cross the carbonate rocks of the aquifer or issue from its springs supply downstream users on the Colorado, Guadalupe, San Antonio, and Nueces Rivers. Residents of Corpus Christi as well as residents of smaller cities and farms along these streams rely on these surface waters for their water needs. Anglers, boaters, and campers also make use of these streams between the springs and the Gulf of Mexico. Finally, flows of fresh waters into the bays of the Gulf are needed to maintain the populations of shrimp and other aquatic species.

An incredibly diverse fauna exists within the Edwards Aquifer, including two species of blind catfish and the Texas blind salamander—*Typhomolge rathbuni*, a federally listed endangered species. Several small aquatic organisms live only in the vicinity of the big springs issuing from the Edwards Aquifer. Other species listed as endangered are fish found in Comal, Barton, and San Marcos Springs—the fountain darter (*Etheostoma fonticola*) and the

San Marcos gambusia (*Gambusei georgei*); salamanders—the Barton Springs salamander (*Eurycea sosorum*) and the San Marcos Springs salamander (*Eurycea nana*); and Texas wild rice (*Zinzania texana*). The San Marcos gambusia, however, has not been observed for almost ten years. Several other aquatic species, such as the riffle beetle in Comal Springs (*Heterelmis comalensis*), are potential candidates for the endangered species list. These species are sensitive indicators of the health of the ecosystems in which they live. Federal laws prohibit any actions that might harm or threaten to harm listed species. Clearly, if humans continue to draw heavily from the aquifer, we will decrease spring flows or dry up the spring systems, and thereby eliminate several species.

The case of the Barton Springs salamander has engendered a curious juxtaposition of many interests. These contending parties include people who wish to build homes in the contributing and recharge zones that feed the springs; those who are concerned about the effects of such development on the habitat of the endangered salamander; those who are concerned about the quality of spring water that feeds a giant pool, which at a comfortable temperature of 68°F allows people to swim in it year-round; and those who wish to bathe in parts of the springs that are now fenced off to protect salamander habitats. Even a seemingly simple task such as cleaning the pool has spawned debate regarding the effects (on water quality and habitat) of lowering the pool level and of different methods to remove algae from rocks in the pool.

These varied demands have created numerous political conflicts, because the use of Edwards Aquifer waters is important economically, socially, and ethically. We desire affordable, good-quality water to meet our needs and to stimulate economic growth. We require water for growing crops, for aquaculture, and for livestock. We want continued spring flows to maintain the parks that cluster around the springs and to rejuvenate and sustain endangered species. At the same time, stream flows must remain viable to meet the needs of downstream users. We need fresh water inflows to the Gulf of Mexico in order to support important habitats there. We also hope for inexpensive solutions to the water situation that are acceptable to almost everyone and that do not require massive bureaucracy, government controls, or loss of personal freedom. However, because of past and projected economic growth in the area, it is clear that the aquifer will be greatly strained and may not be able to meet all these requirements.

As described earlier, recharge of the groundwater carried by the Edwards Aquifer occurs through rainfall and the flow of losing streams. Recharge is not uniform, because it depends mostly on leakage from streams that, in turn, have flows dependent on highly variable rainfall. In addition, the aquifer does not respond instantaneously to variations in recharge, nor does it respond immediately to the pumping of water for the multiple uses mentioned. The historical record shows that an extended drought occurred during the late 1940s and early 1950s and caused the Edwards Aquifer to experience low rates of recharge. Since 1956, however, recharge rates have been relatively high. Also, since the late 1950s, population has grown in regions that draw on the Edwards. It is not surprising then, that the amount of water pumped from the aquifer in the last half of the twentieth century has grown steadily—except during wet periods, which minimize the need to use aquifer water for crop irrigation and watering of lawns. However, what will happen when climatic conditions similar to those of the late 1940s and early 1950s recur?

Clearly, when drier conditions recur, someone will have to go without water. Who will it be? Who should it be? Can we by our actions today avoid these choices tomorrow?

OPTIONS

To meet future water resource needs in southern and central Texas, we must increase supplies of water, decrease water demand, and manage water resources more efficiently. Of course, the traditional way to meet higher demand for water is to find additional supplies. For most American cities in the past century, this approach has meant building surface water reservoirs and pipelines. Fortunately or unfortunately, depending on one's perspective, there are few major potential reservoir sites in this part of Texas because there are few deep valleys to dam and few large streams to fill the reservoirs. Therefore, imported surface water would have to come from a considerable distance—perhaps from eastern Texas—and at a huge expense. Long-distance import of water pumped from other aquifers might be possible, but the potential effect on these aquifers and their users still needs study. Small local reservoirs would help the situation, but in drought years such reservoirs may not fill. Enhanced recharge along the losing streams will help. Enhanced recharge could come from dams in streams that cross the Edwards Plateau, whereby water released from the dams could maintain flow in streams that recharge the aquifer. It is logical to pursue this option, although this approach also will not be effective during droughts. It can be developed on a staged and relatively low-cost basis, but enhanced recharge of the Edwards has met with resistance from downstream users who fear that their supplies will be diminished. Removal of salt from Gulf of Mexico seawater—desalination—would also supply additional water to users of the Edwards, but the costs of developing the infrastructure for this process are very high.

An alternative solution would allow dual distribution systems that could perhaps help to increase water availability. Low-quality water resources from deeper aquifers or recycled sewage waters could be used to meet some requirements. Simple rainwater harvesting systems in residences and businesses for low-quality uses have not been widely explored. And, until there is incentive for people and businesses to implement such plans, there will be no demand for and, therefore, no readily available dual distribution systems. Furthermore, when we consider ways to increase our water supply, we must be aware of the effects of manipulations on our landscape. None of our reconfigurations will be without serious consequence, as shown by the history of California's water wars.[3]

Obviously, we must also try to decrease the demand for water from the aquifer. Although curtailed industrial and residential growth is not likely, water conservation and price increases in the cost of water could have long-term positive effects. Municipalities could charge higher rates for "cosmetic" water uses such as lawn watering. A family of four, for example, could pay a higher rate for water it uses above a predetermined amount estimated to be reasonable for a family of this size. Crafting a public policy along these lines may be politically unpopular, but so will not having enough water to go around. Clearly, water conservation practices must be implemented, yet these alone are unlikely to solve the problem.

Just as water conservation practices can help us use water pumped out of the ground more efficiently, there may be ways to use the aquifer more wisely. Conjunctive use of aquifer water with surface waters would permit us to use either surface or groundwater resources in a manner that could ensure maximum efficiency. For instance, we could use groundwater when stream flows are low and switch to surface water when stream flows are high. Conjunctive use, however, will not solve critical problems when droughts happen. If we knew more details about the aquifer, we might be able to design a pumping strategy to minimize adverse affects on spring flows. Which area or zone of the aquifer will yield the most water with the minimal adverse effects? Can we perhaps augment spring flow?[4] Can we take water from one portion of the Edwards Aquifer and reinject it near the springs so that we can continue to use the aquifer during droughts when its use is most important? Finally, can we design our water treatment and distribution systems so as to maximize their efficiencies? When considering these options, we must always be aware of the limitations of engineered solutions in the face of certain geological realities.

WHAT DO WE NEED TO LEARN AND WHAT IS THE ROLE OF GEOLOGISTS?

We must understand better how the Edwards Aquifer works. To make the best use of this precious natural resource, geological studies can offer some of the insights needed to improve our knowledge of how the aquifer works today, how it has operated in the past, and how it might function in the future.

We need a more in-depth understanding of the aquifer's geology, including the alignment and distribution of fractures, to predict the effects of enhanced recharge and development. We need to develop models that allow us to predict responses to pumping, recharge, and potential contamination. We need to know where the aquifer's zones of greatest porosity and permeability are and how these zones are connected to be able to pump water inexpensively and efficiently. We would like to know where to put industrial facilities so that they will not contaminate the aquifer when they leak. We will require geological knowledge on a far more detailed basis than we have ever needed it before.

Geological studies can also offer the added perspective of time. This enhanced approach can give insight into long-term changes in climate that may have occurred in the region. Historical records of rainfall only go back 60 years. Is this long enough to decipher longer-term trends in climate that may have affected the aquifer and may affect it in the future? What do these records portend for the long-term survivability of the region's endangered species?

The news media highlighted warnings of floods from the El Niño climatic event predicted in the summer of 1997. The event in the following fall and winter proved to be the second largest on record and had significant impact in regions such as southern California. Texas experienced only moderately higher than average rainfall, and this was followed by unusually dry and hot conditions in the summer of 1998. The high temperature and lack of rainfall led the U.S. Department of Agriculture to designate all 254 counties in Texas as agricultural disaster areas. Droughts have been and will continue to be part of the natural climatic cycle of central Texas. It will be necessary to deal with drought conditions as well as the projected increased demands on the aquifer that will occur even in the absence of drought. A combination of scientific efforts might improve our capabilities to project the likelihood of droughts. We must build comprehensive records of past climate change, study shorter-term changes in present atmospheric and earth surface conditions by using the growing technological capabilities of space-based observations, and improve computer model simulations of future climate change.

Although available records for central Texas indicate regular, periodic climatic changes, there are not enough data to know whether the climatic changes have a predictable pattern, what the extremes are, and how the climate varies regionally over time. Are the patterns observed in the 60 years of historical measurement, such as rainfall and temperature, superimposed on longer-term trends? Are there more sudden or extreme climatic events than those observed historically?[5] Geological records of environmental change, such as those found in vegetation and in cave and stream deposits, offer a view of this longer term.

Records of seasonal rainfall variations over the past 300 years in Texas are preserved in the changing thickness of tree rings found in climate-sensitive post oak trees.[6] These tree-ring patterns indicate that the last 60 years of historical records are representative of the periodicity of drought over the past 300 years. The tree rings also show that the severity of the 1950s drought has not been exceeded since 1698 and that the approximate frequency of such extreme episodes may be about once per century.

Are there any glimpses to be found into how climate changed on the Edwards Plateau prior to 1698? A sequence of sediments found in Hall's Cave on the Edwards Plateau reveals the deposition of sediment, plants, pollen, and animals that had been washed, blown, and carried into the cave. The record covers the past 16,000 years and reveals a number of lines of evidence about how the environment above the cave changed during that time.[7] For example, changes through this sequence in the proportions of fossils of the drought-tolerant desert shrew (*Notiosorex crawfordi*) and the non–drought-tolerant least shrew (*Cryptotis parva*) show changes in rainfall. The absence of prairie dogs, which require thick soils for their burrows, in the younger part of the sequence reflects a significant loss of soil in the last 8,000 years. The evidence in the sequence indicates that the drought-prone conditions that we are presently experiencing on the Edwards Plateau have persisted for the past 1,000 years. Unfortunately, century-scale changes are still difficult to resolve. However, new research on calcite speleothems from caves in the Edwards Plateau has the potential to provide high precision, long time-scale records (from decades to millennia) of environmental change. Chemical analysis of microscopic layers of mineral growth in the speleothems is being used to determine the ages of the layers as well as clues to how water flow and possibly climate shifted in this region during growth of the layers.[8]

As is the case with all aquifers, the Edwards is a unique resource because of the geological processes that created it. These processes include the accumulation of marine organisms that originally formed the sediment, the crustal upheavals that faulted and cracked the rocks, and the action of streams that cut through them and influenced the development of caverns. To maximize our understanding of the ability of this resource to serve our growing needs, we need to advance our application of geological studies to the Edwards Aquifer. We need projections based on trends of past natural variability and on models for future population growth, urbanization, rainfall, temperature, and land use. There is much that we do not know about the effects of urbanization on water abundance, water quality, and ecosystems. Gathering this information will require integration of principles used by geologists, climatologists, urban planners, hydrogeologists, and biologists, and the attention of policymakers. Add in the potential effects of atmospheric warming due to anthropogenic greenhouse gas emissions and it is clear that a policy that waits until the eleventh hour to address these issues is a policy that is too risky to follow for the next generation of Texans. We must have geological and hydrological research on the Edwards and other aquifers before the next crisis necessitates political, economic, and legal action. The long-term view of geology offers us the unique perspective to understand how the Edwards Aquifer was built, how it functions now, and how it might function in the future.[9]